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Evolution of Computer Integrated Manufacturing (CIM) Technologies

Version 2.0

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U. S. Department of Transportation
Research and Special Programs
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Durint the past decade a great deal of effort has been focused on the advantages computerization can bring to engineering design and production activities. This is seen in such developments as Group Technology (GT), Manufacturing Resource Planning (MRP) Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and Flexible Manufacturing Systems (FMS). It has also been recognized that greater advantages can be gained if all relevant technologies are merged together into a single integrated system termed Computer Integrated Manufacturing (CIM). While CIM has many connotations, it commonly includes the integration and automation of design, manufacturing and maintenance information, as well as the control of the product, from perception, through production, to shipment and support. the CIM approach encompasses all areas of operation, including engineering design, production planning and control, production equipment, and processing of numerically controlled machines. CIM is a strategy that enables a manufacturing facility to operate as a whole, using an integrated data system, permitting automatted flow of information across the manufacturing facility.
A review of studies is followed by a description of the major components of CIM. Subsequent sections focus on the use of various CIM technologies that have potential impact on the U.S. Air Force environment.

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1. INTRODUCTION

During the past decade a great deal of effort has been focused on the advantages computerization can bring to engineering design and production activities. This is seen in such developments as Group Technology (GT), Manufacturing Resource Planning (MRP), Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and Flexible Manufacturing Systems (FMS). It has also been recognized that greater advantages can be gained if all relevant technologies are merged together into a single integrated system termed Computer Integrated Manufacturing (CIM). While CIM has many connotations, it commonly includes the integration and automation of design, manufacturing and maintenance information, as well as the control of the product, from perception, through production, to shipment and support[1]. The CIM approach encompasses all areas of operation, including engineering design, production planning and control, production equipment, and processing of numerically controlled machines. CIM is a strategy that enables a manufacturing facility to operate as a whole, using an integrated data system, permitting automated flow of information across the manufacturing facility. As shown in Figure 1[5], CIM includes the fields of Computer-Aided Design (CAD), Computer-Aided Planning and Computer-Aided Manufacturing (CAM).

In the past, manufacturing information was moved unidirectionally downstream from design towards product shipment across a number of departments and with little feedback to adjust to the reality of what occurred in production. In a typical organization, the design department produced drawings and bills of material, the production planning department generated the work schedules, the production control office issued ship orders, and the programmers generated the tapes to run numerically controlled machines. The aforementioned scenario describes the current local manufacturing processes at an Air Logistic Center. In this scenario, data are usually exchanged in paper form and they are subject to duplication and human error.

CIM Components

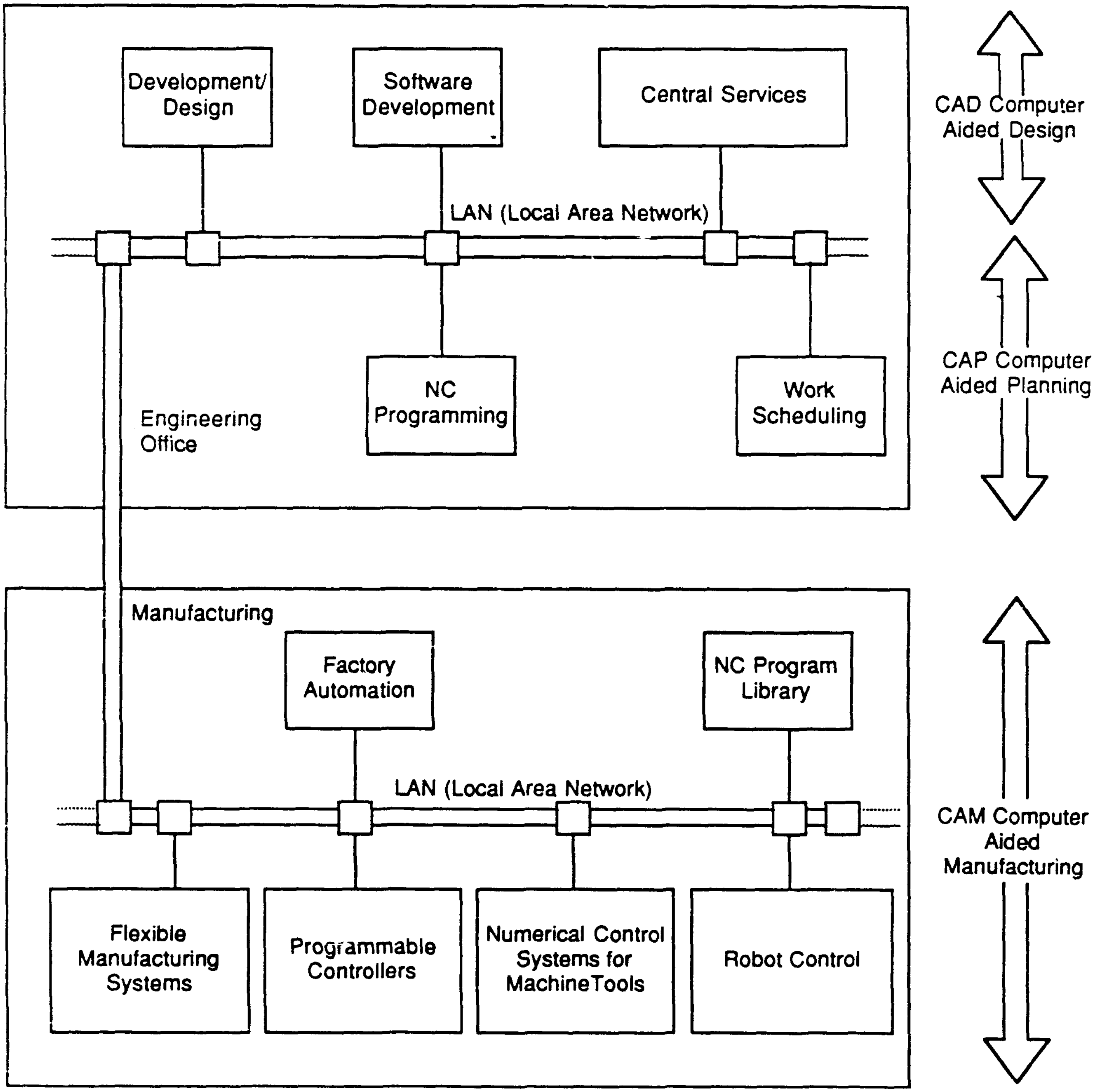


Figure 1

Source: Henderson, M.J., "Economical Computer Integrated Manufacturing", Proceedings of the Fifth International Conference on Flexible Manufacturing Systems, SME, Michigan, 1986.

In a CIM environment, information is transferred bi-directionally across all segments of the manufacturing process. While machine instructions still flow down into the various machine tools and automated material handlers, tool information, such as machine utilization, quality verification, machine down time, and maintenance data, automatically flows back up to the monitoring computers. Such information is used to dynamically alter the manufacturing processes and to optimize the output of the entire manufacturing facility. Bi-directional flow of information increases the effectiveness of the manufacturing planning and scheduling process.

The CIM methodology offers significant benefits in many large application scenarios. Based on an interview of representatives from five top companies, the amount of benefits achieved during the last 10-20 year timeframe from advances in using computers in various types of manufacturing operations are summarized in Table 1 [2]. This table shows that the maximum impact of computers has been in increasing the capability of engineers to perform detailed design analysis in short periods of time. Also, the quality of the products, as measured by the yield of acceptable products, has increased by 2-5 times over previous levels using a CIM approach. The amounts of the reduction of work-in process (30-60%) and the reduction of personnel costs (5-20%) will become more signficant as firms implement more contemporary CIM approaches.

Another study focused on the ultimate technological potential of CIM; this study looked at the long-term potential of current state-of-the-art technology. The views of eight leading experts in five different countries are shown in Table 2 [3]. These experts feel that the maximum incerase will be in terms of enhanced utilization of capital equipment. The benefits are perceived to be more in the areas of product quality (140% increase on the average) and manufacturing productivity (120% increase) than in terms of lead times from receipt of order to shipment (expected reduction by 45%).

Benefits Achieved From Last 10-20 Year Efforts in CIM

Reduction in engineering design cost	15 - 30%
Reduction in overall lead time	30 - 60%
Increased product quality as measured by yield of acceptable product	2 - 5 times previous level
Increased capability of engineers as measured by extent and depth of analysis in same or less time than previously	3 - 35 times
Increased productivity of production operations (complete assemblies)	40 - 70%
Increased productivity (operating time) of capital equipment	2 - 3 times
Reduction of work in process	30 - 60%
Reduction of personnel costs	5 - 20%

Table 1

Source: CAD/CAM Interface Committee of the Manufacturing Studies Board of the National Research Council

Forecast of Ultimate Technological Potential of CIM

Q: What do you estimate to be the ultimate percentage, compared to today, that CIM can achieve in the following:

Abbreviated Questions	Estimates of Respondents	
	Range %	Average %
Increase in manufacturing productivity?	20 - 200	120
Increase in product quality?	60 - 200	140
Decrease in lead time from design of product to initial production for sale?	30 - 90	60
Decrease in lead time from receipt of order to shipment?	30 - 50	45
Increase in utilization of capital equipment?	20 - 1500	340
Decrease in inventory of work in progress?	30 - 90	75

Table 2

Source: Production Engineering Research (CIRP)

The next section of this report describes the major components of CIM. Subsequent sections focus on the use of various CIM technologies that have potential impact on the U.S. Air Force environment.

2. THE COMPONENTS OF CIM

The components of CIM are the hardware devices and the software programs which make up the fully integrated system. These components may be distributed across the design, engineering, and manufacturing facilities. The key element of the CIM effort lies in the integration of these various parts into a cohesive system.

A number of CIM practitioners describe the structure of a CIM system in terms of the levels of automation. In Figure 2[4], these levels are defined from an organizational perspective. The highest level (Level IV) is at the corporate strategic planning level and is primarily dedicated to organizational management functions and product design. Automation at this level reduces the manual effort needed to perform personnel, product design, marketing, and advertising, and finance tasks of the firm. Level III controls the resource planning and accounting functions of the firm. Systems at this level support purchasing, accounts payable, accounts receivable, master scheduling and sales analysis functions. Level II is dedicated to the supervisory and control functions of the manufacturing plant. This level of CIM automates inventory control, capacity planning, engineering data collection, and work in process tracking. This level also offers the capability to control the individual manufacturing work cells and to automate load balancing decisions, tool managment, equipment configuration, cycle count analysis, and maintenance scheduling functions. Level I is concerned with the direct control of the machine tools, robots, and material handling equipment. Finally, Level 0 contains the actual factory equipment. A *total* CIM solution integrates each of these five levels.

Implementation of CIM approaches at various levels requires the use of several underlying technologies. Advances in the different component technological areas are delineated in the following subsections.

Levels of Automation in CIM

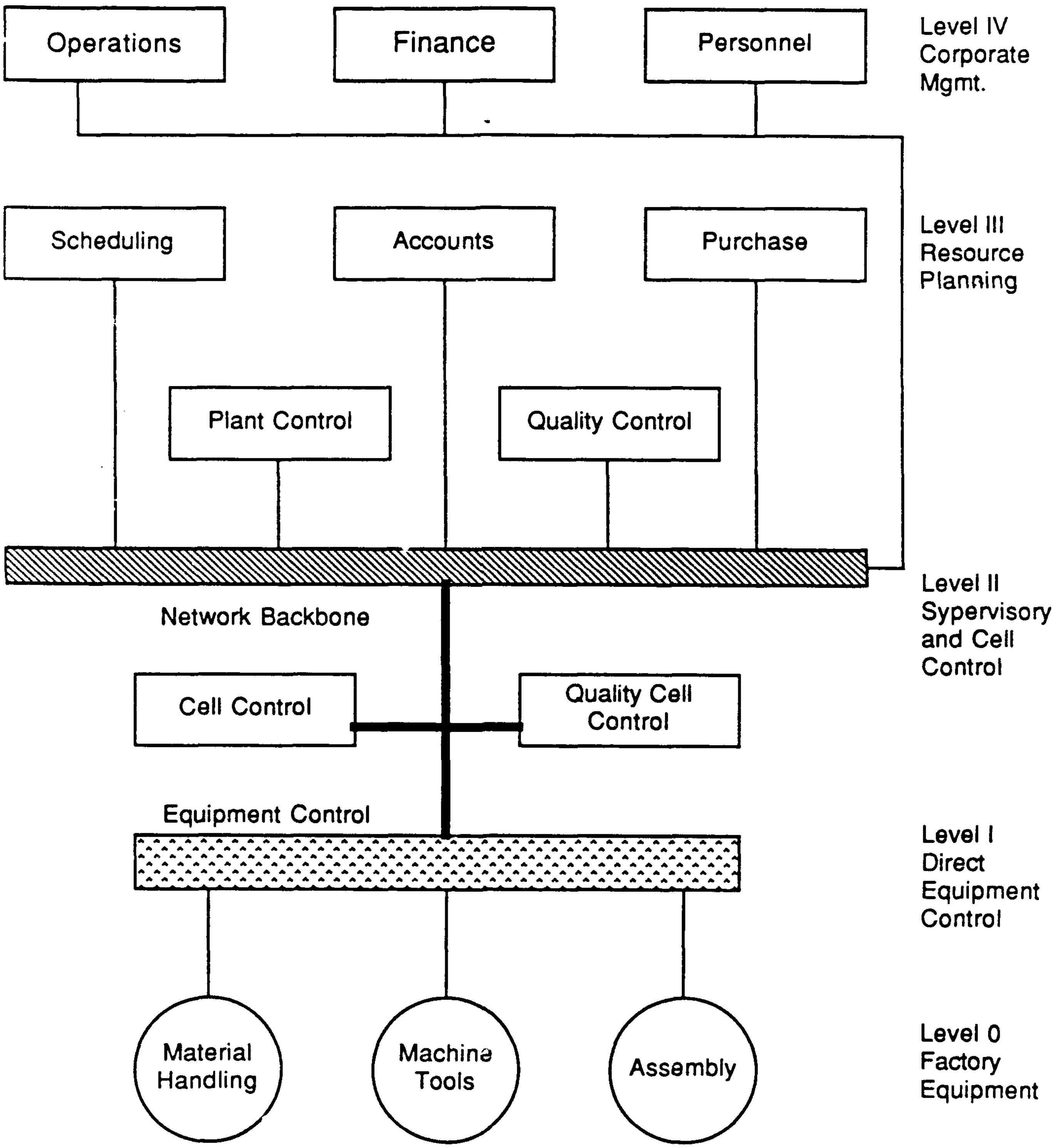


Figure 2

Source: COMETS Software on VAX Computer Supports Shop-Floor Control Within Lot-Based Discret Manufacturing, DEC Brochure, 1988.

2.1 Computer and Communication Technologies

At the heart of the CIM structure are the tools that provide both automation and integration. An array of contemporary hardware, software, and communication components must be carefully selected and integrated together for optimal results. The principal technologies relevant to CIM are listed in Table 3[6] and the key issues are highlighted in the following paragraphs.

In terms of computer technology, manufacturers are standardizing on 32-bit architectures. The diminishing costs of processors encourages use of inexpensive processors in highly-redundant systems that offer very high degree of fault tolerance. Mass storage devices will also become faster by three orders of magnitude. Existing islands of automation will be linked together using new approaches for bridging heterogeneous architectures. The use of fourth and fifth generation languages will drastically decrease the human labor involved in developing software for manufacturing applications.

CIM facilities use Local Area Networks (LANs) to distribute information between computers and production equipment. The protocol used in these LANs is either Ethernet, based on IEEE 802.3, or Token Passing, based on IEEE 802.4. In addition, microcomputers are used as lower level controllers to interface Computer Numerical Controls (CNC), Programmable Logic Controllers (PLC), and other control devices to the LAN system. The use of microcomputers as lower level 'Mini' controllers permits the process control function to be distributed over a large production area, which in turn permits greater flexibility for interfacing and data manipulation. This concept of distributed processing also permits higher level computers to be relieved of tasks better performed at lower operating levels. For example, geometric data generated by the CAD systems can be passed directly to the NC programming system on another workstation, without requiring intervention by the central computer[7].

Table 3
ADVANCES IN UNDERLYING TECHNOLOGIES

Technology	Features	Implications
Communications		
Local Area Networks	Ethernet/IEEE802.3 Token/IEEE802.4	Increased integration Bi-directional flow of information
Protocol Standards	MAP/TOP	Faster data transfer
Cable Technology	Fiber Optics	Increase network application programming
Network Languages	X-Windows	
Hardware		
Supermicrocomputers	32 bit processing	Lower cost of computing and storage
Reliable Mainframes	Much longer uptime	
Mass Storage	1000 plus times faster	Decreased response times
Storage/Access Standards	Bridge heterogeneous hardware	Increased ability to handle complex applications
Fifth Generation	Highly parallel processing	Increased connectivity Enhanced production control
Software		
Fourth and Fifth Generation Languages	Easy to learn, use, port	Increased pace of development Less expensive customization Fewer analysts and programmers required
Expert Systems		
New AI Tools	Emulate human decisions Object-oriented programming	Users take development role Increased user productivity

An important consideration of LAN is the choice of the network transmission medium. Options for a transmission medium range from the simple twisted pair telephone wire to advanced cable technology. CIM facilities utilizing a LAN can use either a 50- or a 75-ohm coaxial cable to transmit data at 100M bits per second over distances of 30 miles or less. A single coaxial cable can provide 120 channels, each of which can handle data at a rate of 128K bits per second. Fiber optic technology is advancing at a considerable rate and is expected to become a standard within the next 10 to 15 years. This medium is currently capable of transmitting at a rate of 45 billion bits per second, and this capacity should increase to 10 trillion words per second within 3 to 5 years.

Advances in communication technologies enables the design operations, the production planning operations, and the manufacturing processes to be linked together, and for information to be transmitted across the entire manufacturing facility on an on-line basis. In the past, the dominant trend was to install the required communication and computational facilities on a turnkey basis. Now, the emphasis is on using off-the-shelf hardware. With an increasing number of CIM minicomputer components being replaced by high performance, low-cost microcomputer substitutes, and the introduction of next-generation CAD systems at a fraction of current prices, even small manufacturing firms will be increasingly impacted by advances in the CIM arena.

Every CIM environment involves the use of a large number of computing units from which individuals can access, modify, and store information, as well as perform specialized job functions. These computing units form the basic building blocks for the CIM environment. The market for these building blocks can be broken into four categories as follows:

1. PERSONAL COMPUTER-BASED SYSTEMS
   - Usually based around IBM PC.
   - Additional coprocessors, graphics boards, memory used.
   - Price around $10,000.

   (Examples: Personal designer, Anvil-1000 MD)

2. ENGINEERING WORKSTATIONS (EWS)
   - Based on stand-alone or interconnected workstation(s).
   - Use contemporary 32-bit microprocessor technology.
   - Price around $25, 000 per station.

   (Examples: Systems based around Apollo and Sun workstation(s).)

3. TURNKEY SYSTEMS
   - Designed for specific applications.
   - Usually hosted on mainframe computers.
   - Average price of $400,000.

   (Example: IBM Mainframe System with CADAM/CATIA Software.)

4. MODULAR SYSTEMS (NON-TURNKEY SYSTEMS)
   - Built around minicomputers such as: DEC VAX 11/7xx Series and DG Eclipse Series.
   - Software developed in-house or procured from third-party vendors.
   - Typical price of $250,000 for hardware and $100,000 for software.

Based on the above categories, the total installed base is expected to evolve to the rate shown in Table 4.

The growth pattern reflected in Table 4 is based on certain assumptions. Technologies relating to communications, hardware, and software are advancing at a

EVOLUTION OF CIM INDUSTRY

INSTALLED BASE BY SEGMENT:

	1984	1988	1992	1996
PC-Based	11,000	72,000	150,000	250,000
EWS	5,000	36,000	70,000	120,000
TURNKEY	8,000	13,000	16,000	19,000
MODULAR	1,000	2,000	3,000	4,000
PENETRATION	11%	35%	65%	90%

TABLE 4

fast pace as shown in Table 5. This rapid evolution enables new systems to operate at faster speeds and to offer greater functionality than earlier systems. The increased power and functionality largely offsets any price reductions. The average price for systems sold in each market segment continues to remain virtually unchanged. These factors have led to the following general trends:

-Increase in market penetration of CIM systems is primarily due to the growing popularity of PC-based systems and engineering workstations.

-Decrease in growth of turnkey CIM systems, in terms of annual percentage rates, in favor of off-the-shelf hardware and software alternatives.

-Decrease in average price per system-function over time.

Overall, the increasing use of off-the-shelf hardware and software in CIM applications has encouraged the growth of such applications.

2.2 Expert Systems

The term "expert system" refers to systems that use contemporary computer technology to store and interpret the knowledge and experience of a human expert, sometimes several experts, in specific areas of interest [14]. By accessing this computer-based knowledge, it is possible to make faster and better decisions in a CIM environment.

The quality of the computer's response is dependent on the quality of the stored knowledge. Unfortunately, the methodologies available today limit the amount of knowledge that can be stored and accessed in meaningful amount of time. This makes it necessary to develop expert systems for relatively "narrow" application areas

IMPROVEMENT IN OVERALL PERFORMANCE

COMPONENT TECHNOLOGIES	Present	1 - 3 Years	3 - 5 Years	5 - 10 Years	MAIN FACTORS
1. Communications	1	50	200	500	Fiber Optics
2. Hardware	1	20	50	200	Micro-electronics and parallel processing
3. Software	1	5	20	50	Object-oriented languages

The numbers above represent the amount of improvement as compared to the present state of commercially-applied technology. The advent of fiber optics will enhance the communications capabilities by a factor of 200 within the next 3 - 5 years. The other numbers should be interpreted in a similar manner.

TABLE 5

rather than the broad domain of CIM.

The two main components of an expert system are its knowledge base and its inference mechanism. The former contains the formal representation of the information pertaining to a particular domain (problem-domain knowledge), while the latter provides the mechanism for interpreting the contents of the knowledge base in the context of a particular situation (problem-solution knowledge). In early expert systems, developed during the 1970s, the focus was primarily on the inference engine. Such systems are usually classified as first generation systems. Second-generation systems distinguish between the knowledge base and the inference engine. Most currently available expert systems fall under this category. Research continues on the development of the third generation of systems with more sophisticated knowledge-restructuring and inferencing capabilities than their predecessors [15].

Whereas current expert systems deal with "shallow" knowledge, the next generation of systems will focus on "deep" knowledge. In other words, such systems will be able to reason using the principles and the practices pertinent to the CIM environment rather than just facts. Also, these future systems will be developed with the capability to restructure the knowledge, and also with the ability to access and to interact with other expert systems and large databases in an intelligent and coordinated manner [14].

Perhaps the most significant trend is towards the building of larger, more powerful, and faster expert systems. By 1990, it is expected that a typical expert system will contain about 10,000 rules; this number will increase dramatically to around a billion rules by the turn of this century [16]. The ability to store a vastly increased repertoire of rules, supported by faster systems in the form of highly parallel computers and optical computers, will enable next generation expert systems to be capable of storing comprehensive knowledge about all aspects of manufacturing, including design of parts, fabrication of parts, scheduling of jobs,

coding of designs for purposes of group technology, selection of machining parameters, ordering of raw materials, and development of updates and modifications to existing parts.

Current use of expert systems in CIM industry has been in four major areas as follows:

(i) Engineering Design: Systems in this category embody design rules and practices of human engineers and product designers. The evolution has proceeded in two different dimensions: the first is for configuring functionally complex systems built from a set of standard subsystems or components and the second is for design and engineering of manufacturing products, usually as an adjunct to CAD software packages.

(ii) Manufacturing Planning: Systems in this area help perform computer-aided process planning and CNC programming functions. Each of these application functions has continued to evolve independent of the other. These two related concepts are being gradually merged together making it feasible to implement truely integrated design-manufacturing systems.

(iii) Manufacturing Control: Systems of this type help provide close control over the overall manufacturing process through efficient production scheduling. These systems can generate detailed schedules for the fabrication and assembly operations at the production shop. Of particular importance to CIM is the ability to provide directions to, as well as to receive data from, downstream manufacturing operations.

(iv) Factory Automation: Systems of this nature assist in the planning of overall factory operation and in the simulation of flexible manufacturing environments. Simulation software aids are now available to facilitate the design and the development of automated work cells, manufacturing systems, and FMS factories. Another set of software is being developed for supervisory systems that can coordinate the operation of automated manufacturing and material handling equipment.

It is pertinent to mention here that the use of expert systems in a CIM environment provides the mechanism to exercise careful control over the entire manufacturing process and to make on-line decisions whenever unexpected events occur. Two areas that will be heavily impacted by innovations in expert systems technology are Computer aided Process Planning (CAPP) and Computer Assisted Quality Assurance (CAQA).

2.3 Flexible Manufacturing Alternatives

An increasing number of American industries are pursuing various CIM options with the objective of maintaining and improving their competitive edge. Traditionally, companies have classified themselves as either being a producer of goods to order, or a producer of goods for stock. This is the distinction between a job shop and a mass producer. As a result of the need to meet changing requirements and shorter production cycles, producers are merging job automated equipment and operating concepts oriented towards high production volumes. Their intent is to create a manufacturing structure that can adapt to changes in products and product-mixes with minimal time and effort needed for changeover. This concept is exemplified by Flexible Manufacturing Systems (FMS) and similar flexible manufacturing alternatives.

The term "Flexible Manufacturing Systems" (FMS) connotes a group of numerical control (NC) machines controlled by a central computer and connected via a network to automated material handling equipment, machine tools, and robots. An FMS is designed to simultaneously produce several types of parts in a given product mix, which remains the same in the short-run, but the mix changes in the long-run. The FMS is constructed from a complex set of flexible machine tools which are capable of processing a sequence of different parts with negligible tool set-up time.

The key word in FMS is "flexible." Flexibility embodies eight basic characteristics as described below [8]:

- **Machine Flexibility:** The ability, without human interface or record set-up times, to replace worn-out, broken tools; change tools in a tool magazine; assemble or mount the required fixtures.
- **Process Flexibility:** The ability to vary the steps necessary to complete a task; allow several different tasks to be completed in the same system using a variety of machines.
- **Product Flexibility:** The ability to change over to produce a new product, within the defined part spectrum, very economically and quickly.
- **Routing Flexibility:** The ability to vary machine visitation sequences and to continue producing the given set of part types.
- **Volume Flexibility:** The ability to operate an FMS profitably at different production volumes.
- **Expansion Flexibility:** The capability of expanding a system easily and modularly.
- **Production Flexibility:** The ability to quickly and economically vary the part spectrum for any product that an FMS can produce.

Based on the level of flexibility available on a system, and the amount of production volume envisaged, there are different categories of systems. The major categories are described in the following paragraphs[9].

Stand-Alone Machines

A stand-alone machine is a single machining center or a turning center with limited automatic material handling capabilities. The stand-alone machine offers

probing, inspection, tool monitoring, adaptive control, and other features that are typical of a fully automated flexible system; however, all these features are initiated and directed at the machine control level. As compared to a machine center or a turning center, a stand-alone machine offers the facility of multiple pallets and/or chuck changing arrangement. This additional facility permits unattended operation for extended periods with minimal operator intervention. The concept of stand-alone machines is ideally suited for manufacturing of small quantities of many dissimilar parts. In the long-run, larger manufacturing capabilities can be configured around these stand-alone machines.

Flexible Manufacturing Cells (FMC)

The Flexible Manufacturing Cell (FMC) is best suited for applications where a large variety of similar parts are manufactured in relatively small numbers. The FMC can be configured in a number of ways. It has more than one machine tool with some form of material handling and pallet changing equipment such as an industrial robot or other specialized equipment. Generally, the cell utilizes a common pallet or part fixturing device for specific part requirements. The FMC supports a fixed process, and parts flow sequentially between operations. The cell is controlled by a dedicated computer unit with real-time routine, load balancing, and production scheduling instructions.

An FMC is essentially the basic building block of a FMS. Smaller and medium sized firms begin an FMS project by first incorporating small isolated manufacturing cells. This is sometimes referred to as phase-one FMS. A scaled-down isolated cell, which may consist of two or three machines capable of material handling, pallet changing, host computer and management information communication, is considered to be a stepping stone to a larger, facility-wide system. Over time, the single FMC evolves into multiple Flexible Manufacturing Cells and subsequently into a distributed cell-integrated FMS. In this FMS, each FMC serves as a basic module of the system, and the different cells are interconnected together by a LAN. Because of its high inherent flexibility, the growth of distributed cell-integrated FMS is expected

to occur at a faster pace than all other FMS approaches.

Flexible Manufacturing Systems (FMS)

A Flexible Manufacturing System (FMS) includes at least three elements: a number of work stations, an automated material handling system, and a system supervisory computer control. An FMS is typically designed to run for long periods with little or no operator attention. While an FMS meets the need for machining in a batch environment where approaches dedicated to high-volume production (such as transfer lines) can be cost prohibitive, it can also react quickly to product and design changes. Centralized computer control over real time routines, load balancing and production scheduling is a primary element of all FMS environments. The FMS concept is most relevant for moderately heavy production volumes.

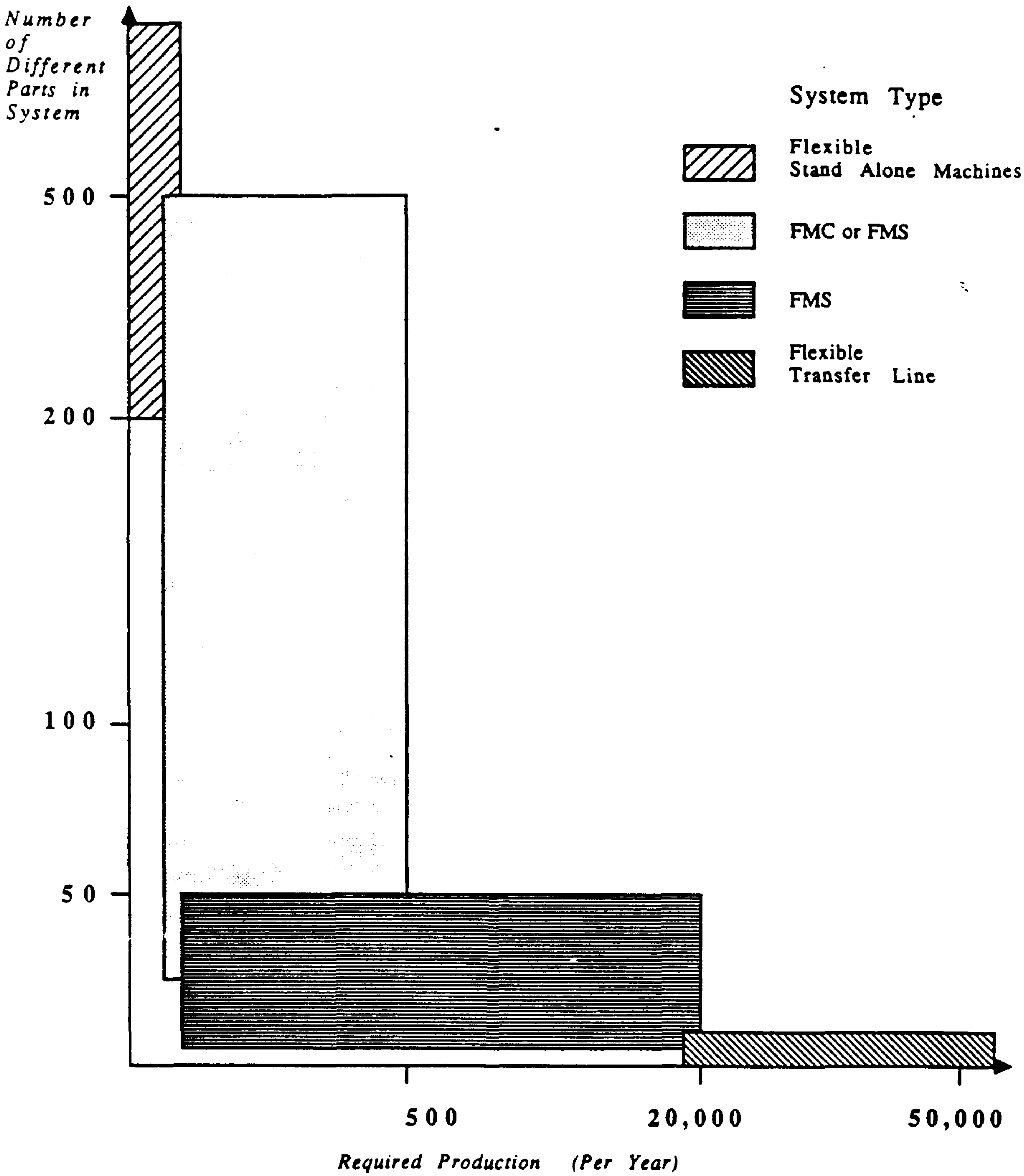
Flexible Transfer Lines (FTL)

With a Flexible Transer Line (FTL), each operation for all part types is performed on only one machine. This results in a fixed routine for each part through the system. The layout is process driven. The material handling device is usually a carousel or conveyor. The storage area is usually local and lies adjacent to each machine. Unlike the FMC, this alternative is less process flexible and less capable of automatically handling breakdowns.

The various flexible manufacturing options are suitable for different environments based on number of different parts and quantities of each part. As shown in Figure 3[9], stand-alone machines are most relevant at low production volumes, while transfer lines are most appropriate at the high end.

FIGURE 3

Guide to Best Suited Manufacturing System



Source for Data: U. S. Department of Commerce, A Competitive Assessment of the U.S. Flexible Manufacturing Systems Industry, U. S. Government Printing Office, Washington, D.C., 1985.

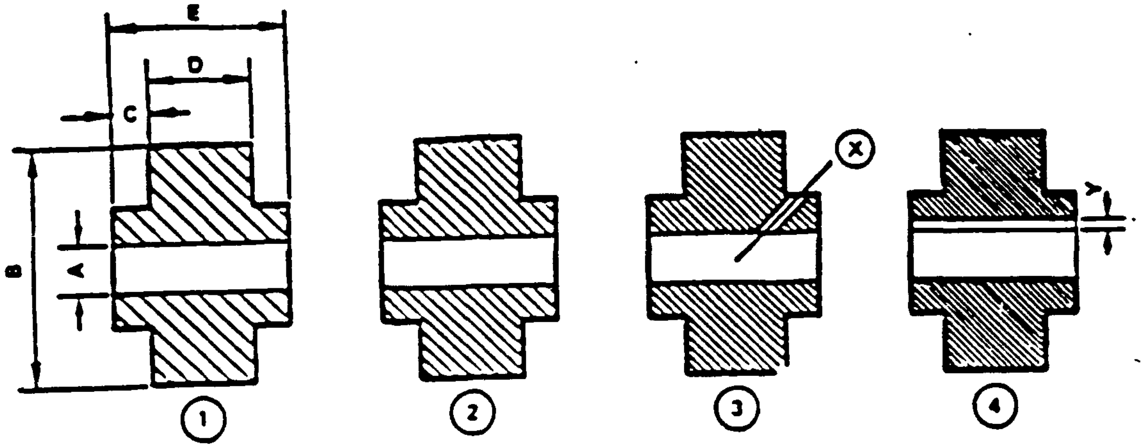
2.4 Group Technology

Group Technology (GT) is a concept that is attracting increasing attention from the manufacturing community. Group technology is an advanced approach to batch manufacturing which seeks to maximize efficiencies in small-lot production by taking advantage of similarities that exist among component parts. The fundamental idea is simple: identify and group related parts and processes; formulate these into "families" on the basis of design and manufacturing similarities (for example, five hundred parts may be grouped into twenty-five families of related features); then look for potential economies by reducing product design, improving manufacturing engineering, and rearranging production layouts. When parts are systematically organized by design, component variety is decreased as designs become standardized, duplication of design effort is reduced by using previous drawings, and the design process is accelerated by using a coding scheme for data retrieval. When GT is applied to the manufacturing process, production efficiencies are enhanced by reducing work-in-process inventories, shortening product and machine set-up times, and simplifying production facility layouts.

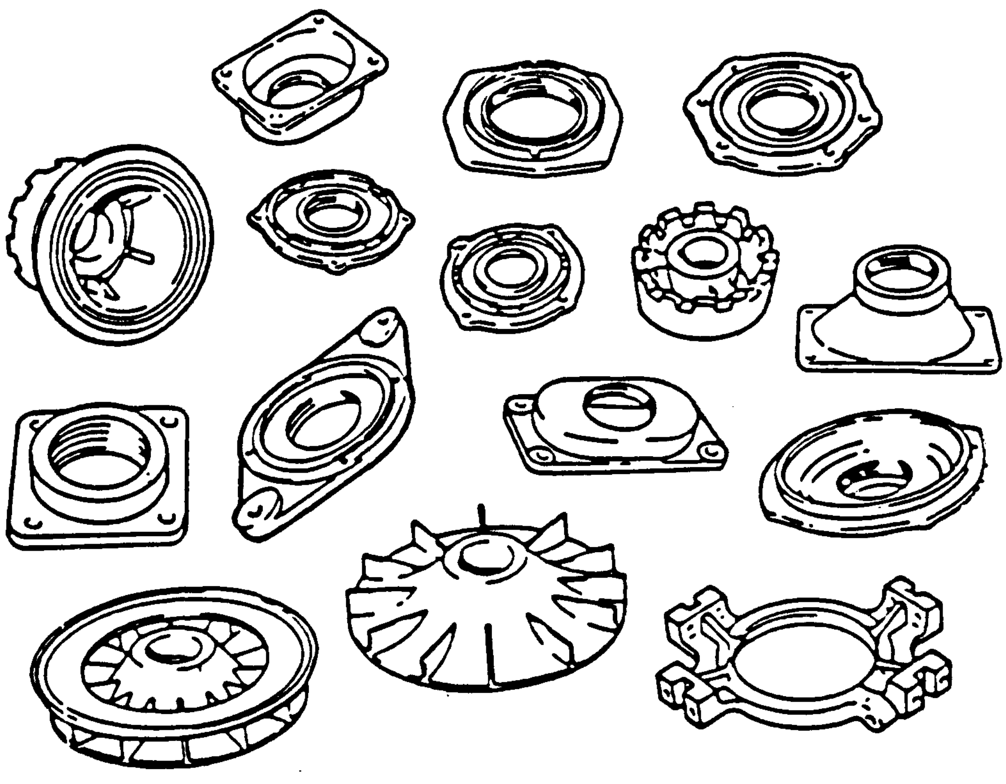
Group Technology forms the basis for development of integrated computer aided procedures. Using the GT method, parts are first classified by technological characteristics (shapes, dimensions, materials) and process characteristics (flow, machine tools) are then coded according to the attributes that describe them. The four parts shown in the top half of Figure 4[10] are similar in shape, but are fabricated using different materials. The parts in the bottom half of Figure 4[10] are of different shapes, but they all involve very similar manufacturing operations. By careful analysis, it is feasible to classify and code these parts into "buckets of similar parts" [10]. The design and manufacturing processes are then optimized for groups of parts, rather than for each part.

FIGURE 4

Similar Parts Based on Shape



Similar Parts Based on Manufacturing Process



Source: Hyer, Nancy Lea (editor), Capabilities of Group Technology, The Computer and Automated Systems Association of SME, 1987, pp. 62 - 63.

A study by Arthur D. Little, Inc., shows that in a typical design environment, if one takes a tally of all parts used in a new design, roughly two-fifths of the total number are existing parts, another two-fifths of the parts can be created by readily modifying existing parts, and only the remaining one-fifth of the parts are truly new. The tremendous potential for improving productivity through selective grouping is highlighted in Table 6[12], which shows that production and quality control costs, setup times, throughput times, and work-in-process inventory can be concurrently reduced by more than 60 per cent by using Group Technology in place of traditional approaches.

For Group Technology concepts to be relevant, there must be some degree of similarity across parts; also, the production mix must be known in advance to ensure optimal scheduling. The cost and the effort involved in using Group Technology have dropped significantly as shown in Table 7[13].

2.5 Robotics

A robot is defined by the Robot Institute of America as "a programmable, multifunction manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks." This definition, which emphasizes physical tasks is considered too narrow by some experts, who feel that the term also includes robots used for information gathering and data handling[28,29].

A robot consists of two main functional components as described below:

- The manipulator consists of links and joints that can move in various directions enabling the robot to perform a diverse range of tasks. The links are usually driven by actuators.
- The controller serves as the brain of the robot. It is responsible

Reported Benefits Associated with Group Technology

52% reduction in new parts designed

10% reduction in number of drawings through standardization

30% reduction in new shop drawings

60% reduction in industrial engineering time

20% reduction in production floor space required

45% reduction in scrap

80% reduction in production and quality control costs

69% reduction in setup time

70% reduction in throughput time

82% reduction in overdue orders

42% reduction in raw materials inventory

62% reduction in work-in-progress inventory

60% reduction in finished goods inventory

33% increase in employee output per unit time

Table 6

Source: Hyer, Nancy Lea (editor), Capabilities of Group Technology, The Computer and Automated Systems Association of SME, 1987, p. 68.

TABLE 7

EVOLUTION OF GROUP TECHNOLOGY

Coding Method	Numerical Representation	Keyword Assistance	Relation GT	Relational feature GT
Ease of Use	Cumbersome	Less Cumbersome	Flexible/integrated	AI Assisted/Expert Systems Natural Language
Interface	Batch/non-interactive	Menu Driven/interactive	Menu/Icon Driven	Menu/Icon/Voice Driven
Hardware	Mainframes	Mainframes/Minis	Mainframes to Micros	Workstations & PCs
Average Cost for Implementation	$200k	$150k	$100k	$50k

← 1970s → ← 1980s → ← 1990s →

Source: Franzosa, R. G., Relational Group Technology, Computer Assisted Process Planning and the Future of Manufacturing Automation, SME Seminar, New

for:

(a) Starting and terminating the movement of the manipulator in a particular sequence;

(b) Storing programmed data and commands; and

(c) Communicating and interacting with the outside world.

The performance of a robot is determined primarily by three factors as described below:

- The type of motor-driving control. The robot can be driven by pneumatic, hydraulic, or electric means. Pneumatic robots offer least precision. Electrically driven robots, though more expensive than both types of robots, are most suitable for assembly type applications.

- The degree of robot-arm freedom. This factor defines the number of axes through which the arms or manipulators of the robot can deal with. In the simplest case, the robot-arm can move along three Cartesian axes- x, y, and z. Usually, more complicated motion paths are supported.

- The availability of servo drivers. This is the main factor that separates simple robots from more intelligent ones. The non-servo controlled robots move their manipulators in an open-loop fashion between exact end points, while the servo-controlled robots provide greater flexibility and are suitable for complex tasks.

Robots are usually fabricated with an array of internal and external sensors that help them recognize position, velocity, size, or orientation of items that they are dealing with. The percentage of total robots with multiple sensors, is predicted to be as follows[19]:

	1985	1990	1995
Robots with vision	5.5%	15.0%	26.6%

Robots with tactile sensors	5.1%	13.3 %	25.4%
Robots with other sensor	6.1%	16.0 %	25.8%

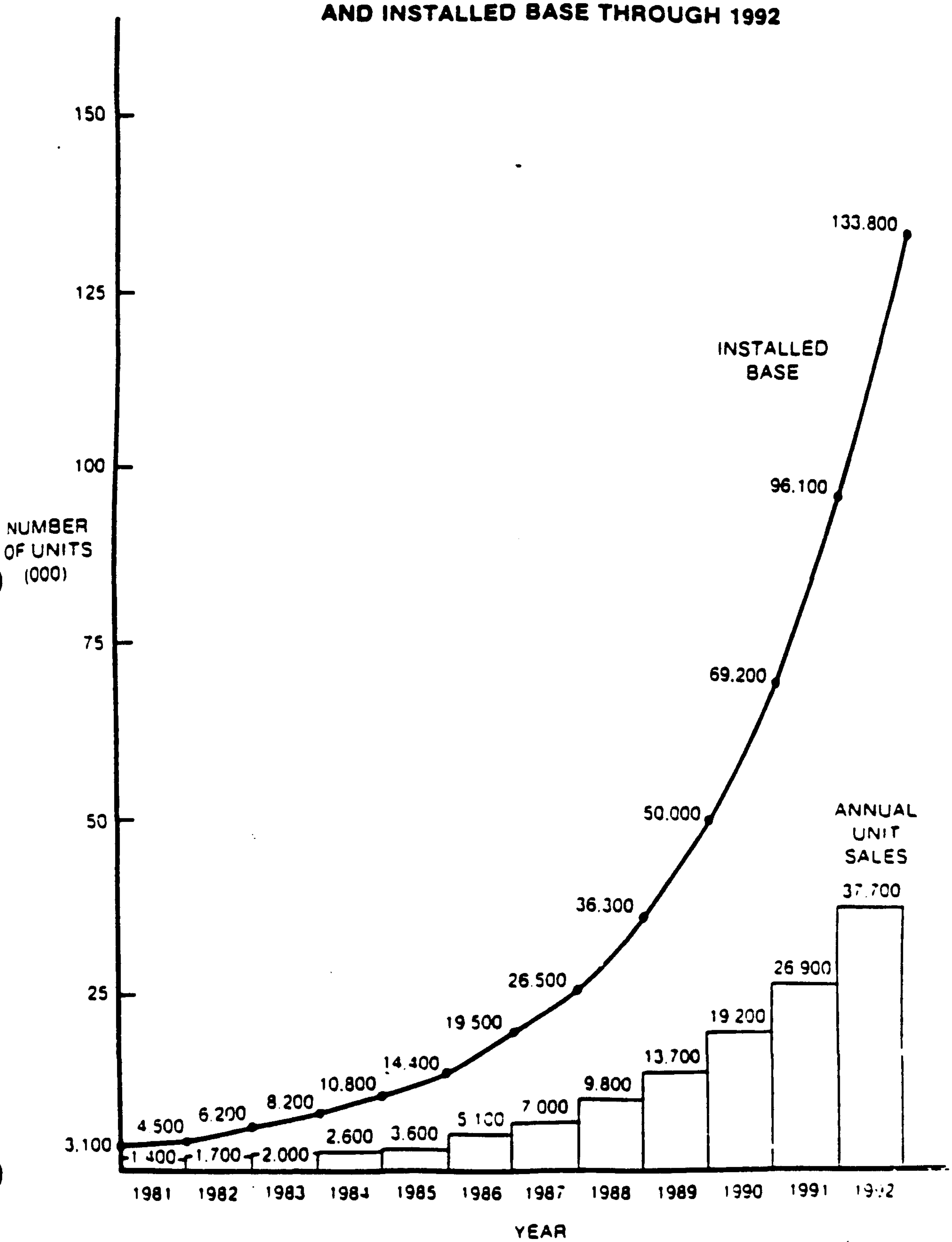
By 1995, it is expected that 17.8% of the robots will be equipped with more than one type of sensor. This percentage is ten times the corresponding percentage for 1985. The increased availability of sensors will enhance the number of applications that can benefit from use of robot technology.

The total number of robots installed and the annual sales are shown for a 12 year period in Figure 5[20]. The exponential shape of the curve highlights the fact that robots are beginning to be accepted as valuable units in many diverse manufacturing applications. Robots are expected to be used in about 50 - 60% of all manufacturing applications for which they are suitable by 1992. The projected annual market will exceed $1 billion in 1990, and $2 billion in 1992. Apart from the growth in terms of numbers and dollars, there is also a shift in the kinds of applications that contemporary robots are being utilized for. This shift is depicted in Figure 6[21]. Whereas the most favored application for robots was spot welding in 1982, the emphasis will be on materials handling, machine loading, and machining in 1992.

A Delphi study conducted jointly by the Society of Manufacturing Engineers and the University of Michigan concluded that the biggest impediment to the implementation of CIM-controlled robots is the lack of a viable economic justification. The second key impediment is the lack of ability to interface with existing factory equipment. Because of these reasons, there continues to be significant management resistance to the acquisition of robotic technology.

Figure 5

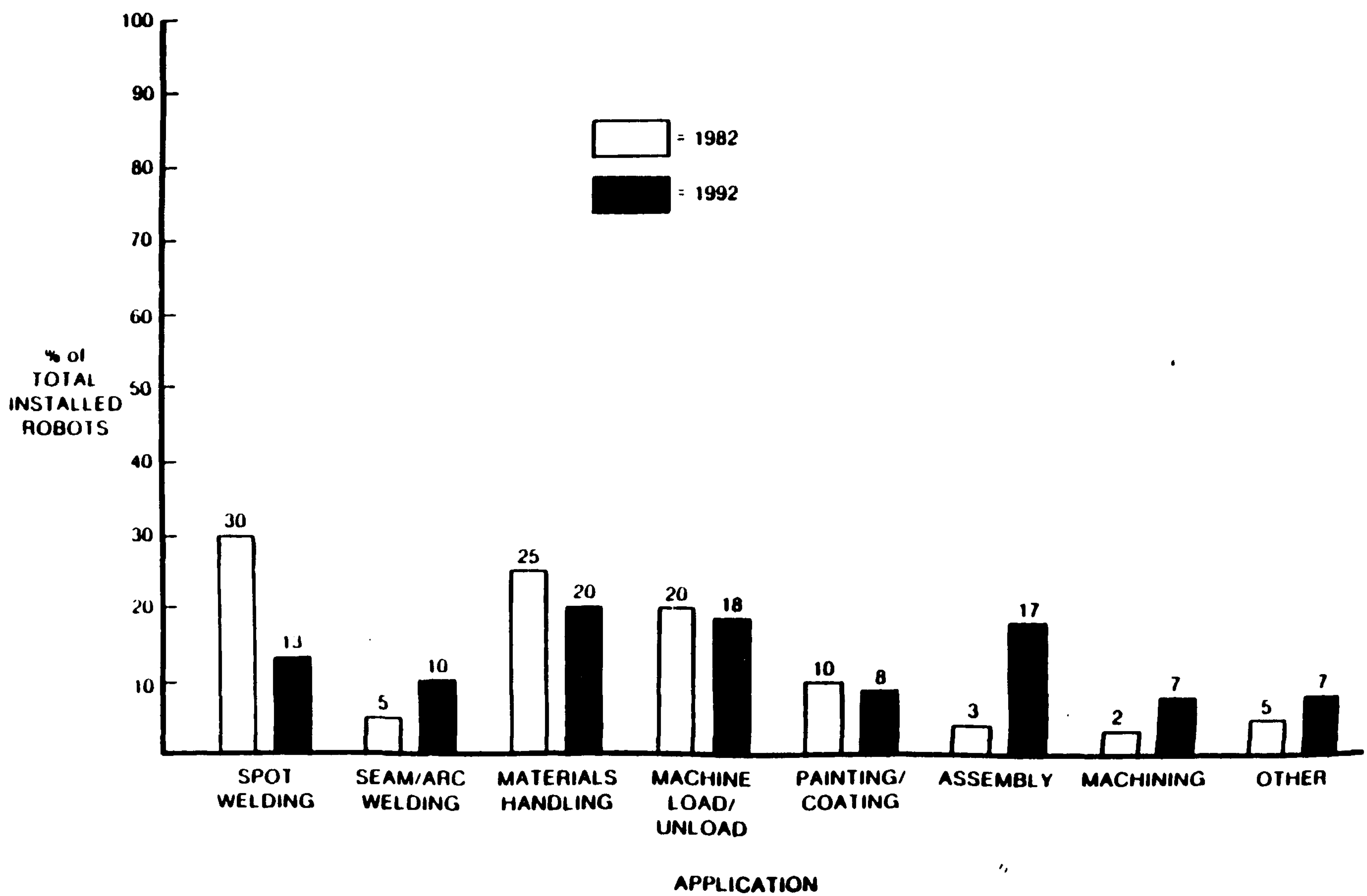
PROJECTED ANNUAL UNIT ROBOT SALES AND INSTALLED BASE THROUGH 1992



Source: Industrial Robots Summary and Forecasts, Tech Tran Corporation, Illinois, p. 214.

FIGURE 6

U.S. ROBOT APPLICATIONS, 1982 VS. 1992



Source: <u>Industrial Robots Summary and Forecasts</u>, Tech Tran Corporation, Illinois, p. 219

2.6 Computer-Aided Process Planning (CAPP) and Computer-Aided Quality Assurance (CAQA)

Process planning is defined as the task of translating design specifications of a part into manufacturing instructions. This function takes approximately 40% of the preparation time for a new part. Traditionally, it is performed manually by highly skilled workers who possess in-depth knowledge of the manufacturing processes involved and the capabilities of the machine tools. A detailed knowledge of the particular manufacturing environment is necessary because it imposes constraints on the available alternatives. The objective is to produce a detailed process plan which includes machine tools to be used, sequence of operation, tool and fixture selection, and cutting conditions. Computer-Aided Process Planning (CAPP) can generate process plans faster and with better consistency than human process planners.

The objective of CAPP is to assist in the development of process plans using two fundamentally different approaches: (i) variant or retrieval approach; and (ii) generative approach. In the variant approach, a number of standard or partially blank process plans are stored on the computer for a variety of parts, and a standard process plan is then selected based on the design data. The ability to make a correct selection, without human intervention, can be implemented using expert systems technology. In the generative approach, stored data and design information are used to generate an exhaustive list of all feasible process plan alternatives. This list is analyzed to identify the optimal plan. The analysis time can be drastically reduced using expert systems technology. While the objective is to perform the process planning operation automatically, current systems still require human intervention. In spite of this weakness, CAPP products provide considerable improvement in planning efficiency, estimating efficiency, and tool standardization [27].

Quality Assurance is currently performed on a labor-intensive basis in most

cases. Even when Computer Aided Quality Assurance (CAQA) techniques are utilized, the inspection and the assurance tests are performed on an off-line basis. These off-line techniques increase productivity to a limited extent. A study by Texas Instruments shows that inspection times for parts can be reduced by a factor in the range of 4 - 60 [18]. Still higher benefits can be obtained by merging the quality assurance procedures into the CIM environment. Such a scenario permits defective parts to be automatically dispatched to appropriate machines for corrective action. Operations on these machines by the central CIM scheduling algorithm based on priorities of various jobs. CAQA then becomes an integral aspect of the CIM system, rather than remaining an activity to be performed after the final manufacturing operation.

As companies integrate an increasing number of their functions, the concept of CAPP and CAQA are becoming broader than before. One example of this phenomenon is the concept of MRP. This term originally meant "materials requirements planning", and connoted a planning system for ordering and managing inventory. The new version, commonly designated as MRP-II, implies "manufacturing resources planning" and includes functions "not only to tie together and summarize the various data bases in the factory, but also to juggle orders, inventory and work schedules, and to optimize decisions in running the factory"[30].

CAPP techniques are increasingly relying on Group Technology[30, 31]. Traditionally, a process planner looked at the drawing of a new part and decided the machine tools to use, and the sequence of operations. This resulted in a very large number of process plans because of two reasons. First, different planners usually came up with dissimilar process plans for same or similar parts. Second, process planning was performed with a particular configuration of machine tools in view, and as new machine tools were acquired, new process plans were developed without eliminating old ones. The use of Group Technology permits a systematic look at all similar parts, and the use of the same plan for multiple parts. This facilitates optimization of overall operations. A company using 51 machine tools and 87

different process plans to produce 150 parts was able to produce the same number of parts using only 8 machines via 31 process plans[32]. Apart from more efficient process planning, CAPP leads to lower unit costs by reducing labor, material, tooling, and inventory costs.

Most FMS systems are designed with some level of CAPP and CAQA capabilites. Designers usually distinguish between two types of quality assurance tests: probing versus inspection. Probing refers to short dimensional inspection routines which are carried out on the machining center, while inspection implies dimensional inspection executed on advanced integrated NC inspection devices. In 1986, the percentage of the aggregate FMS systems in the U.S. with both probing and inspection capabilities was 21.7%, which was higher than that for any other country. At the same time, the percentage of the total FMS systems in the U.S. with neither capability was 34.8%; this percentage was significantly lower in Belgium, Italy, and Germany[33]. In all countries, there is a trend to incorporate inspection and probing capabilities into the FMS configuration.

The components described above form the basis for emerging CIM approaches. In the next section, these approaches are examined in the context of the aerospace industry.

3. CIM IN THE AEROSPACE INDUSTRY/AIR FORCE ENVIRONMENT

The key components of CIM technologies were identified and discussed in the preceding section of this report. In this section, these technologies are examined in the context of the aerospace industry and the Air Force environment. Specific instances of the use of these technologies are highlighted. The last part of this section focuses on the forces that are currently impeding the widespread acceptance of CIM technology.

AEROSPACE INDUSTRY

Aircraft production differs from other types of manufacturing in the following aspects[34]:

- Manufacturing operations are labor intensive.
- Part geometry is largely non-standard.
- Production lots are small and part costs are high.
- Tooling costs are high.
- Control systems are complex and unwieldy.
- Mix of manufactured parts is unique.
- Production facilities lack flexibility.
- Product designs are evaluated by non-cost criteria.
- A variety of processes are utilized.

A large fraction of the work is performed by contractors and subcontractors, imposing limitations on the roles of each company, and the types of information that can be transferred from one company to another.

AIR LOGISTICS CENTERS

The ALCs produce parts in small lot sizes to meet immediate maintenance requirements. The list of items manufactured by Warner Robins Air Logistic Center for cost avoidance or urgency of need during FY87 shows quantities in the range of 2 to 46 units. Given the small number and the unpredictable pattern of the items to the items to be manufactured at the ALC depots, it is essential to provide them with as much manufacturing flexibility as possible.

In the following subsections, the relevance of different CIM technologies is explored in relation to the aerospace environment.

3.1 Flexible Manufacturing Systems

A partial list of the aerospace companies using FMS equipment is shown in Table 8. Virtually all major companies are using some type of FMS facilities. There is no single supplier of CIM equipment who dominates the list. In terms of hardware used, equipment from Digital Equipment Corporation is used in the FMS facilities at roughly half of the companies listed in Table 8.

An FMS system operating at Vought Aerospace in Dallas since 1984 is now claimed to be "capable of economically producing lot sizes of one. Cincinnati Milacron, which built the system, calls it the most sophisticated FMS in the world"[34].

Flexible Manufacturing Systems are being used by many companies for manufacturing mechanical parts for the aerospace industry. Companies like IBM are using these systems for manufacturing and testing printed circuit cards. Earlier, the feeling was that FMS was relevant only in cases involving very large production volumes. The experience in a number of situations showed that apart from the fact

Table 8

USE OF FMS EQUIPMENT IN AEROSPACE INDUSTRY

USER	OBJECTIVE	SUPPLIER OF FMS EQUIPMENT	HOST SYSTEM
Boeing Aerospace	Manufacture missile components	White Sundstrand	OMNI
Boeing Aircraft	Manufacture aircraft parts	Shin Nippon Koki	DEC
General Dynamics	Manufacture aircraft components	Westinghouse/ DeVlieg	Proprietary
Hughes Aircraft	Manufacture castings for aircraft and missile parts	Kearney and Trecker	PDP 11
McDonnell Douglas Astronautics	Manufacture parts for missiles	Giddings and Lewis	G & L
Rockwell International	Manufacture axles	Kearney and Trecker	Bendix
Sundstrand Aviation	Manufacture aircraft components	Kearney and Trecker	DEC GEMINI
Vought Aero Products	Manufacture 540 parts for B-1 bomber	Cincinnati Milacron	PDP 11

that the large FMS configurations involved very heavy investments, larger systems were less flexible as compared to smaller systems. As such, more companies are now preferring to go for Flexible Manufacturing Cells. The market for these cells is growing at a rate of 40-50% per year and is expected to be worth $540 million in 1989[35]. These cells are appropriate both in manufacturing environments as well as in ALC depots.

3.2 Group Technology

The concept of Group Technology was originally conceived for the traditional machine tool environment. In such a case, the manufactured products typically differed from each other in terms of physical sizes and type of materials. Automobile companies and other large companies such as Deere and Caterpillar adopted these technologies. Aircraft manufacturers began using these concepts for optimizing use of existing tools and generation of NC programs. For example, Boeing Uniform Classification and Coding System (BUCCS) covers commercial airline parts manufactured by Boeing [36]. Also, General Dynamics adopted Group Technology concepts from a mechnaical orientation. They felt that "modern aircraft are made up of 50% or more sheet metal parts...; 68% of the detail parts are typically ordered in one quantities...; small individual production quantities are an aid to Group Technology application because they allow a significant reduction in production costs by scheduling part families for production rather than individual parts and thereby artificially increasing the lot size" [37].

Most large aerospace contractors are today utilizing group technology concepts for production of mechanical parts. Coding and classification of parts has been done either on a division basis or on a corporate basis. There is no standardization of codes across companies in the aerospace sector.

As far as electronic items are concerned, Hughes Aircraft claims to be the first to apply Group Technology in the manufacture of electronic products. In late 1983, they began work on using this technology in the production of approximately 70,000 circuit card assemblies in 1,200 different configurations [38]. Group Technology is currently used by IBM and other large companies to assemble circuit boards and other electronic assemblies.

3.3 Robotics

Robotic technology is being applied at many aerospace companies for structural processes such as welding, riveting, and drilling. Robots are also being increasingly used for more complicated operations such as assembling, materials handling, and machine loading/unloading. Overall, "while the aerospace industry is frequently at the forefront of robotics technology research and development, the overall rate of utilization lags that of commercial industry. This finding is driven largely by the small production rates typical of aerospace industry" [39].

The ALCs are currently pursuing, with the assistance of Honeywell, detailed analysis of 12 areas for the application of robotic technology. These areas include assembly, disassembly, cutting, sorting, and automated storage operations. Criteria for selection included low technical risk, generic applicability, worker health and safety, reduced flow time, reduced production costs, and improved quality[40].

From a technical viewpoint, the use of robots is highly desirable in many CIM environments. However, the low production volumes, the costs involved in applying robotic technology, and the lack of ability to interface with existing factory equipment are three reasons that impede widespread usage of this technology.

3.4 Constraints and Limitations

The problems that characterize the robot industry also plague the whole CIM industry. Despite the tremendous benefits from CIM, the concept has not progressed at the rate earlier predicted by industry forecasters.

The biggest overall limitation of CIM is the sheer magnitude of the undertaking. Many companies are intimidated by the amount of planning and implementation effort necessary to get a CIM system operating effectively. While large companies can consider investing in FMS, medium and small companies are obliged to restrict their investment to replacement of old machines on a piece-meal basis, and to adhere to traditional methods of stand-alone NC with all the associated overhead of paper tapes, shop worksheets, paper-bound drawings and part lists[22]. The amount of funds needed for modernization, the production volumes needed to justify new technology, and the fact that government contracts are based on a cost-plus basis system are some of the major disincentives to major investments in CIM.

One of the biggest questions faced by any organization interested in automating its manufacturing operations is the initial approach and strategy. One solution is to establish "islands of automation" by automating only one process or one machining center at a time, evaluating the results, and then deciding on whether or not to automate further. This, however, eventually leads to the major problem of incompatibility across automated islands. Some consultants advocate that a company start with a small FMS, while others advocate starting with an MRP system. Currently, there is no consensus on the optimal or preferred approach.

Control Engineering magazine polled several companies in the control industry that successfully manufacture and use CIM products and systems. No one company was able to offer all of the components and services needed for a complete CIM

installation. The set of vendors included planners (third party consultants), computer hardware vendors (IBM, DEC, etc.), industrial control vendors, system integrators, material handlers, and software companies. To improve interconnection compatibilities, most control equipment vendors have standardized on either IBM or DEC computers.

The Manufacturing Studies Board of the Commission on Engineering and Technical Systems has pointed out that integration of various CIM components is presently constrained by problems at three levels[23]:

- The limited ability of different programs to communicate together even on the same computer.
- Communication problems which exist between computers even of the same brand.
- Communication problems among a variety of manufacturers' systems.

Major attempts at mitigating the above problems are discussed in the succeeding paragraphs.

Manufacturing Automation Protocol or MAP is a communcations protocol specification for a manufacturing local area network (LAN) environment. It was initiated by the Advanced Product and Manufacturing Engineering group at General Motors Technical Center. This standard has gained acceptance of over 100 American manufacturing companies. Further, since MAP is based on the popular seven-layer ISO standard, it is attracting endorsements from foreign companies, especially in Europe. In spite of growing worldwide computer vendor support, MAP is still an evolving standard. For example, release 3.0 of MAP is not compatible with release 2.1[24,25]. In addition, there are extensions such as carrier-band MAP and Enhanced Performance Architecture[26]. An extension for the optical fiber environment is under consideration. The presence of these extensions, and the

incompatibility between different versions of MAP reduces some of the benefits of MAP. In spite of these weaknesses, the market for broadband LAN systems conforming to MAP standards is expected to exceed $137.1 million in 1989.

Technical and Office Protocol or TOP is a companion to MAP specification. The specification of TOP is being spearheaded by Boeing. While MAP is intended for use on the factory floor, TOP is intended for use in the office environment, with appropriate links to the factory floor. While both MAP and TOP comply with the seven layer ISO architecture, MAP uses a token bus, broadband communications network as its physical link, while TOP uses a baseband specification, with broadband to be used only in certain circumstances. Of the seven layers, layers two through six are essentially identical between the two standards. As such, products conforming to MAP will be able to communicate with TOP oriented products with little data conversion problems.

Government Open Systems Interconnection Profile or "GOSIP is consistent with and complementary to industry's Manufacturing Automation Protocol (MAP) and Technical and Office Protocols (TOP)"[41]. GOSIP permits multiple options at most layers, and the definitions for several of these options have not yet been finalized. As such, GOSIP specifies a framework of standards (rather than one standard), which is currently intended to encompass both MAP and TOP. As such, products adhering to MAP will automatically meet the specifications of GOSIP.

Product Data Exchange Standard (PDES) encompasses the totality of data elements which completely define a product for all applications over its expected life cycle. To meet this approach, PDES uses a three-layer architecture. Because of its very broad charter, its dependence on voluntary support from individuals, and the time and effort involved in reconciling different views and objectives, it will take several years for PDES to be a key force in the CIM industry. At the present time, the effort is focused on Version 1.0 which includes models for mechanical parts, mechanical assemblies, printed wiring assemblies layout and construction, AEC

models, FEM and drafting. Many areas critical to CIM, such as form features, tolerances, solids modeling will be addressed only in subsequent versions of PDES.

The fact that standards are still evolving makes it difficult to decide on the type of equipment to acquire at this stage. Suggestions in this regard are presented in the next section of this report.

4. CONCLUSIONS AND RECOMMENDATIONS

CIM is not a single technology, but a spectrum of interrelated technologies, each characterized by its own set of innovators, its own range of constraints and impediments, and its own characteristic pace of evolution. The technology that links and encompasses all the individual pieces, that is, the technology of efficient and intelligent interconnection, is itself subject to an array of pressures from government, vendors, and users. Given these facts, it is difficult to make technology assessments for CIM as a whole, as compared to its constituents such as CAD and CAM.

At this stage, it appears certain that a single CIM approach is unlikely to meet all the requirements of the Air Force. On one side, there are large contractors and subcontractors who manufacture standard parts in large quantities; on the other, there are ALCs who produce parts in small lot sizes to meet immediate maintenance requirements. In addition, there are requirements for reprocurement of spare parts and for developing modified versions of parts to be used on the entire weapon fleet. Given this diversity of requirements, it is pertinent to look, not for a single CIM approach, but for an optimal portfolio of CIM approaches.

4.1 Key Findings

Section 2 of this report analyzed trends in seven major areas: Computer Processing, Communications, Expert Systems, Flexible Manufacturing Systems, Group Technology, Robotics and Computer-Aided Process Planning and Quality Assurance. All these areas are expected to change significantly between now and 1995, and the principal changes are summarized in Table 9. The salient aspects are highlighted in the following paragraphs.

TABLE 9

MAJOR FINDINGS

Area Manufacturing	Current Capabilities	Future Capabilities
o PROCESSING		
- Programming/Software	DATA ORIENTED/CONVENTIONAL	OBJECT-ORIENTED/EXPERT SYSTEMS
- Configuration	ISLANDS OF AUTOMATION	INTEGRATED HETEROGENEOUS ENVIRONMENT
o COMMUNICATIONS		
- Data Transfer	ONE DIRECTIONAL	BIDIRECTIONAL
- Medium	CONVENTIONAL	FIBER OPTICS
- Protocols	EVOLVING	STANDARDIZED
o EXPERT SYSTEMS		
- Operation/Knowledge	STAND-ALONE/LIMITED	INTEGRATED/INTELLIGENT
- Number of Rules Supported	5,000	10 MILLION BY 1995
o FLEXIBLE MANUFACTURING		
- Usage	LIMITED	WIDESPREAD WITHIN 8 - 10 YEARS
- Types of Parts Handled	RESTRICTED	RELATIVELY BROAD
o GROUP TECHNOLOGY		
- Approach	HUMAN - DEPENDENT	EXPERT SYSTEMS ORIENTED
- Coding Methodology	NUMERICAL	RELATIONAL
o ROBOTICS		
- Areas of Emphasis	MUNDANE TASKS (e.g. painting, spot welding)	COMPLEX TASKS (e.g. material handling, part assembly)
- Sensor Capability	30% of UNITS	60% by 1995
o OTHERS		
- CAPP	WEAK LINKS WITH CIM	INTEGRATED INTO CIM
- CAQA	OFF-LINE AND OPEN LOOP	ON-LINE AND CLOSED LOOP

FLEXIBLE MANUFACTURING SYSTEMS

Flexible Manufacturing Systems are already being used up by major contractors. The technology relating to mechanical parts is more advanced than that of electronics items. There are some instances where Flexible Manufacturing Systems are more cost-effective than conventional systems even when a single unit has to be manufactured. The concept of Flexible Manufacturing Cells will become widespread as these cells continue to grow at a rate of 40-50% per year and exceed $540 million in 1989. These cells are less costly and more flexible than larger Flexible Manufacturing System alternatives.

GROUP TECHNOLOGY

Group Technology concepts are already being widely applied in many aerospace companies. In virtually all cases, each company, or its division, has developed a unique coding scheme. There is great potential for standardizing codes across companies. Also, instead of relying heavily on analysis by human experts, the coding and classification operations will be increasingly performed with the assistance of Expert Systems.

ROBOTICS

As far as Robotic Technology is concerned, the areas of emphasis will shift from mundane tasks (such as painting and spot welding) to complex tasks (such as assembly and material handling). The percentage of robots with sensor capability will increase from 30% today to 60% by 1995; more significantly, the percentage of robots with multiple sensors will increase from 1.7% today to over 17% by 1995. This dramatic increase will widen the areas in which robots will be used.

COMPUTER PROCESSING

In the area of Computer Processing, next generation computer hardware will incorporate new concepts from the realms of microelectronics and parallel processing. By 1995, overall performance of computer hardware is expected to

improve by a factor of 200 and that of computer software by a factor of 50 as compared to today's hardware and software. The traditional emphasis on data oriented systems will shift towards object- oriented systems, in which the object will encompass both the data and the program code that pertains to that data. New techniques will be designed and developed to integrate existing heterogeneous information systems together.

FIBER OPTICS

Fiber optics will become the standard technology for meeting communication requirements of all CIM endeavors. The use of fiber optics offers the potential for enhancing bandwidths by a factor of 500 as compared to today. In parallel, GOSIP (including its subsets of MAP and TOP) will reach a stable, well-defined stage. These facts will facilitate integration of equipment of diverse makes, models, and capabilities.

EXPERT SYSTEMS

While current expert systems deal with "shallow" knowledge, the next generation of systems will focus on "deep" knowledge. In other words, such systems wil be able to reason using the principles and the particles pertinent to the CIM environment rather than just facts. Future expert systems will also possess the ability to interact with large databases and other expert systems in an intelligent and coordinated manner. CAPP and CAQA are two innovative technologies in the area of expert systems.

CAPP/ CAQA

The dual areas of Computer-Aided Process Planning and Computer-Aided Quality Assurance will benefit from increased integration in companies and across companies. The DMMIS system at ALC depots does not presently specify any on-line exchange of data with flexible manufacturing technologies. Today, when computers are used in quality assurance tests, these tests are typically performed on an off-line basis. CAPP and CAQA will become increasingly incorporated into the

CIM environment, leading to lower unit costs by reducing labor, material, tooling, and inventory costs. Also, future systems will permit on-line access to information maintained in databases of other contractors and subcontractors.

SUMMARY

Technologies relevant to CIM are advancing at a fast pace. This rapid evolution enables new systems to operate at faster speeds and to offer greater functionality than earlier systems. The increased power and flexibility largely offsets any price reductions.

No single company can offer all of the components and the services needed for a complete CIM installation. The set of vendors includes planners (third party consultants), computer hardware vendors, industrial control vendors, system integrators, material handlers, and software companies. Even in each of these segments, there is no clearly dominant force in any of the segments, with reference to the CIM market. Because of the wide diversity in the types of CIM hardware, software, configurations, and processes, information relating to the manufacture of a particular part at one company cannot be readily used by a different company.

4.2 Recommendations

Attempts at standardization of products data by PDES will not have a major impact on the CIM market until the mid-late 1990s. Instead of waiting for them, it is appropriate to adopt an implementation startegy that provides benefits both in the interim period as well as in the long term.

The major recommendations of this study are as follows:

1. Aerospace contractors should be encouraged to use CIM technology. The

type of CIM facility depends on the characteristics of the specific situation. Appropriate mechanisms should be used to motivate contractors and subcontractors to use contemporary technology.

2. The concept of Flexible Manufacturing Cells is best suited for applications where a large variety of parts are manufactured in relatively small numbers. This concept can be applied at ALC depots. These cells provide optimization of resources as well as adequate flexibility for the kinds of items manufactured at these depots.

3. The concept of Group Technology should be considered when assigning part numbers. Group Technology allows significant improvements by making use of the similarities across families of parts.

4. The feasibility of industry-wide coding and classification of parts should be examined. At the minimum, group technology concepts can be gainfully utilized within the context of each weapon system.

5. All equipment procured by the government, or with government funds, should fit within the GOSIP framework.

6. A companion study concluded that it was not advantageous to do raster-to-vector conversions given the rate of evolution of raster-to-vector technology and 3-D solid modeling techniques. As such, conversion of existing data to IGES formats is not recommended.

ALC depots can gainfully employ the above mentioned CIM technologies to produce the current mix of parts. These facilities can be augmented in the 1990s when contractors provide data for new weapon systems in stable PDES format.

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